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Computational Schlieren Photography with Light Field Probes

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Abstract We introduce a new approach to capturing refraction in transparent media, which we call light field background oriented Schlieren photography. By optically coding the locations and directions of light rays emerging from a light field probe, we can capture changes of the refractive index field between the probe and a camera or an observer. Our prototype capture setup consists of inexpensive off-the-shelf hardware, including inkjet-printed transparencies, lenslet arrays, and a conventional camera. By carefully encoding the color and intensity variations of 4D light field probes, we show how to code both spatial and angular information of refractive phenomena. Such coding schemes are demonstrated to allow for a new, single image approach to reconstructing transparent surfaces, such as thin solids or surfaces of fluids. The captured visual information is used to reconstruct refractive surface normals and a sparse set of control points independently from a single photograph.

Keywords Computational photography · Light transport · Fluid imaging · Shape from x

1 Introduction

The acquisition of refractive phenomena caused by natural objects has been of great interest to the computer vision and graphics community. Co-designing optical acquisition setups and reconstruction algorithms can be used to acquire refractive solids, fluids, and gas flows (Ihrke et al. 2010), render complex objects with synthetic backgrounds (Zongker et al. 1999), or validate flow simulations with measured data. Unfortunately, standard optical systems are not capable of recording the nonlinear trajectories that photons travel along in inhomogeneous media. In this paper, we present a new approach to revealing refractive phenomena by coding the colors and intensities of a light field probe. As illustrated in Fig. 1, the probe is positioned behind an object of interest and the object and probe are photographed by a camera. Due to refractions caused by the medium, apparent colors and intensities of the probe change with the physical properties of the medium, thereby revealing them to the camera or a human observer.

The idea of optically transforming otherwise invisible physical quantities into observed colors and changes in intensity is not new. In fact it occurs in nature in the form of caustics. These types of phenomena are generally referred to as Shadowgraphs but reveal only limited information of the underlying physical processes (Settles 2001). More sophisticated techniques to visualizing and photographing gas and fluid flows, refractive solids, and shock waves were developed in the 1940s (Schardin 1942). Some of the phenomena that were depicted for the first time include the shock waves created by jets breaking the sound barrier and bullets flying through the air, or the heat emerging from our bodies. As illustrated in Fig. 2 (left, red lines), traditional Schlieren setups require collimated illumination, which is then optically disturbed by changes in the refractive index of a medium. A lens deflects all light rays so that the "regular" or unrefracted rays are focused on one specific point (usually the center) of some plane. The "irregular" or refracted rays intersect that plane at different points, which are determined by the angle and magnitude of the refraction. Optical filters such as knife edges or color wheels can be mounted in that plane to encode these properties in color or intensity changes. Further

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